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FINAL REPORT

THERMAL ION DYNAMICS EXPERIMENT (TIDE) and the PLASMA SOURCE INSTRUMENT (PSI)

NASA Contract NAS8-38189
SwRI Project 15-3348

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and the
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FINAL REPORT
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SwRI Project 15-3348

Submitted to:

NASA Marshall Space Flight Center
Huntsville, Alabama

Prepared by:

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SUMMARY

This is the final report for NASA contract NAS8-38189 issued to the Southwest Research Institute (SwRI) for the development of the Thermal Ion Dynamics Experiment (TIDE) and the Plasma Source Instrument (PSI) now being successfully flown on the POLAR spacecraft.

This report contains the following:

I. A narrative summary of the development and operational status of the TIDE/PSI investigation.

II. A review of the operations anomalies that occurred during the first months of instrument operation.

III. Flight software patches developed to correct in-flight anomalies.

IV. A list providing the status of deliverable items enumerated in the contract.

V. A review of subcontracts.

I. DEVELOPMENT STATUS

Following calibration at the Marshall Space Flight Center, the Thermal Ion Dynamics Experiment (TIDE) and the Plasma Source Instrument (PSI) were integrated onto the POLAR spacecraft. The instruments are now in orbit and operating successfully with the exception of several anomalies described in Section II below.

The successful development of the TIDE and PSI instruments was demonstrated during the formal pre-flight calibration and spacecraft integration activities. As expected, several post-launch modifications were required to the flight software. While no software adjustments are known to be needed at this time, the SwRI maintains a fully operational support facility in which to create such modifications if required.

II. OPERATIONAL ANOMALIES

Following is a narrative summary provided by Dr. Craig Pollock, formerly with MSFC and presently a member of the SwRI staff.

A. UV Light Leaks in the TIDE Instrument

There are two known sources of UV contamination in the TIDE instrument. By far, the most serious of these is due to a large light leak (referred to as sneak path light leak), probably located at a seam in the sensor exterior, where the curved sheet metal mates to the flat panel at the bottom of the TOF section. The amplitude of the spin modulated count rate spike due to this noise source can reach 105 Hz in the STARTS when the spacecraft is in the noon/midnight orbital configuration. This amplitude is sinusoidally modulated by season, reaching a minimum of less than 104 Hz when the spacecraft is in dawn/dusk orbital configuration.

This noise source is mitigated by measuring it near apogee (with mirrors shut down) for ten minutes every 2nd orbit and using the results to define a 32 x 32 (1024) element background mask which is routinely subtracted from observed instrument 1024 element count rate arrays.

Impact Assessment:

1. Labor intensive background subtraction required.

2. Background subtraction imperfect solution. Precludes low level measurements near sun pulse peak in 1024 element array.

Lessons Learned:

1. Joint should have been rabbitted, at a minimum.

2. Leak could have been discovered with a 4pi sr UV survey during test and calibration.

3. Potential for leak could have been detected at final launch site inspection. Tape could have eliminated problem.

A more minor light leak (referred to as bore sighted light leak) is detectable when the RPA/Mirror assembly is sighted toward the sun. This leak results in a relatively low level noise source which, strangely enough, is modulated by the applied RPA bias. The mechanism for this modulation is unclear, but noise typically appears at the largest RPA voltages only.

Impact Assessment:

Only minor science impact.

Lessons Learned:

Difficult to totally eliminate UV entrance through aperture.

B. Loss of Mass Analysis Capability

Within a couple of months after launch, it became evident that the TOF spectra were shifting toward shorter times of flight. This effect was not observed to be uniform across TIDE channels but was first and most prominently observed in the lower channels, becoming nearly monotonically less prominent with increasing channel number. This situation was observed to deteriorate with time. Eventually (through the northern summer of 1996), the H+ peak was observed to disappear off the left axis of a count rate vs. TOF bin plot, first on the lower channels and subsequently on the remaining channels; however, by the end of September 1996, no discernable H+ peaks were discernable in the TOF spectra of any channel. Additionally, the peaks associated with heavier ion species were observed to evolve to lower TOF bins and smaller amplitudes (see TOF vs. time spectrogram set, attached). The result was that by the end of September 1996, TOF spectra were pure flatlines in all seven TIDE channels. All TOF functionality had been lost. The only STARTS at this point were those due to UV light leaks, and the only TOF coincidences were accidental.

This state of affairs has been mitigated by executing a software patch such that full 1024 element spin-energy distributions of the STOP rates are now reported in telemetry. The TIDE STOPS continue to function nominally. In fact, the STOPS are the most sensitive signal path in the instrument and the least susceptible to saturation.

Strangely, in February 1997, after the TIDE instrument had been down for a couple of days due to an unanticipated instrument reset, structured TOF spectra with a clearly discernable H+ peak was observed in channels 1 and 2 (the first to fail during summer 1996) when the instrument HV was ramped back up. Since that time, as of this writing, these returned signals have disappeared again, although it may be that vestiges remain.

Testing with the onboard electronic pulsers shows nominal performance and tends to vindicate all electronics beginning with and downstream of the pre-amplifiers. Two hypotheses have been forwarded regarding this problem. One hypothesis appeals to a reduction of START MCP efficiency to incident START electrons due to contamination (by Hydrazine or plastics in the sensor). It is difficult to know, however, how contamination could be the cause in view of the continued robust START rates due to the sneak path sun pulse described above. The second hypothesis calls for some process (perhaps associated with EUV bombardment or hydrazine contamination) to have reduced the secondary electron yield of the ultra thin carbon foils. Such a scenario is consistent with the data, as it is known. However, LANL has conducted tests, exposing foils to a solar UV simulator and measuring evolution (growth) of pinholes in the foils. They found no significant growth in pinhole size or count over several hundred hours of illumination. Similar experiments, using direct measurement of secondary electron yield, have yet to be conducted.

Impact Assessment:

1. Total loss of mass spectrometer function on TIDE. This failure represents critical loss of functionality, which seriously degrades the scientific value of the TIDE data set.

2. Loss of START signals yields loss of channel identification and the intended 2D directional nature of TIDE instrument response. This is an additional significant loss of functionality which further degrades the scientific value of the TIDE data set.

3. The silver lining is that STOPS are most sensitive signal, with least susceptibility to saturation. High quality spin/energy ion flux distributions are being obtained with heretofore never achieved sensitivity.

Lessons Learned:

1. Mechanism for this anomaly is not known. Important implications for other instruments flying MCPs and ultra thin carbon foils (the mechanism is unknown especially if any peaks "come back" etc.) are recognized. It would be highly desirable to determine this mechanism. Tests at LANL are so directed but so far have yielded negative results.

C. PSI Operations Learning Curve

The operation of PSI early in mission life was characterized by several minor anomalies associated with learning how to operate the source. None of these had adverse effects on flight hardware. A mode of PSI operation has been identified that effectively clamps the spacecraft potential near +2 Volts, allowing routine observation of previously unobservable low energy terrestrial polar ion outflows. Unfortunately, the operation of PSI produces environmental modifications, which result in either real or imagined adverse effects on several other Polar instrument data sets. Interference with PWI wave observations and with EFI DC electric field observations is clearly present. Subtle interference with HYDRA low energy electron observations has also been claimed by the HYDRA PI, but this claim has yet to be demonstrated. The UVI PI continues to express concern regarding the chemical effect of released Xenon on the UVI MgFl filters, but, again, no basis for legitimate concern has been demonstrated.

Impact Assessment:

1. By far, the most impact of the situation described above is that political opposition, within the Polar SWG, to routine operations of the PSI source is fairly intense. In practice, PSI has been operated less than 1% of the time since Polar was launched. We have now secured an agreement to begin operations at a 20% duty cycle (2 weeks on, 8 weeks off). This schedule will allow synoptic TIDE observations of the polar outflows, assuming no instrument failures during the next one or two years.

D. Sensitivity to Energetic Particles in the Earth's Radiation Belts.

The sheet metal cover over the TIDE sensor is not thick enough to provide sufficient shielding of the detector systems from energetic particles (and daughter products such as Bremstralung x-rays) associated with the Earth's radiation belts. Large (saturating) count rates are observed in the TIDE START and STOP detectors during periods (twice per orbit) when Polar flies through these belts.

This situation has been mitigated by reducing the high voltage applied to the START and STOP MCPs, using predictive orbit data and time tagged commanding sequences. This plan has been effective in protecting the MCPs from excessive counting through these spatial regions.

Impact Assessment:

1. START and STOP MCPs are effectively shut down (HV reduced below operating levels) for all geophysical L values less than 8.0 by time tagged commands. This method effectively eliminates availability of TIDE observations in the inner magnetosphere - namely plasmaspheric observations. This constitutes a significant, though not critical, degradation in the scientific value of the TIDE data set.

Lessons Learned:

1. This situation was not correctly anticipated by most members of the TIDE development team. Mitigation of this lack of shielding prior to launch could easily have been achieved at the cost of 1 or 2 kg of mass added to the sensor cover in the form of energetic particle shielding, however, this mass was not available. This seems a small price that could have been paid to retain the plasmasphere observations and avoid the intensive (and somewhat risky) HV operations that we have adopted in flight.

E. Failure of TOF HV Enable Function

Shortly after launch, it was noted that the TOF high voltage command enable function had failed such that the negative 15 kV HV supply is permanently enabled. Cause for this anomaly is unknown, although the suspected part is an opto-coupler in the enable circuit. Since the Auto Sensitivity software was designed to safe the TIDE HV by disabling the TOF and MCP HV supplies in the event of any persistent anomalously high count rates, the failure of the TOF enable function required a patch to the flight software, such that TOF HV safing is executed by commanding the TOF HV level to zero, rather than disabling that supply. This patch was written, has been implemented in the TIDE flight software, and works well.

Impact Assessment:

1. No significant impact on TIDE scientific data.

2. Some resources expended to work around as described above.

F. High Voltage Operation Anomaly

When the TIDE -15 kV HV was ramped for the first time on orbit, it was noted that when the command level reached near -10 kV, the monitor seemed to begin to sag below the commanded HV level. It is not known at this time whether this represents a sagging of the monitor only or a true sag in the achieved HV level. As a result of this anomaly, we have operated with the TOF HV supply at a commanded level of -9 kV through the life of the mission up to this point. It is now known what measures may be taken to mitigate this anomaly. If the loss of TOF is due to loss of foil efficiency, then raising this voltage would increase efficiency and possibly allow TOF to operate.

Impact Assessment:

1. No significant impact on TIDE science is recognized, as long as the situation does not deteriorate. No evidence of deterioration has been noted since the anomaly was first noted. TIDE has probably suffered some measure of reduced sensitivity due to the 9 kV operating limit imposed, but this is estimated to be at the 10% or 20% level.

III. SOFTWARE PATCHES

The following software patches were implemented up to and including the development of a “STOP” data product.

The following TIDE flight software patches were prepared during the time period of March 18, 1996 and November 22, 1996. Note that the names of the patch files referenced in this document and transmitted to MSFC may not be the actual names of the patches transmitted by the Polar POCC.

IMPLOCK.DL (March 18, 1996)

This patch was developed to verify a potential TIDE hardware anomaly. This patch was used to remove the software check for the +15 kV supply enable status and allow the +15 kV control Digital-to-Analog Converter (DAC) to be commanded. This patch was used to confirm that the +15 kV supply was permanently enabled due to a hardware anomaly.

PATCHEN.DL (March 21, 1996)

The purpose of this patch is to allow those dataloads that have an F0 through F5 in the function code location to be treated as a normal dataload command. Spacecraft mode commands do not operate with this patch in place.

PATCHDIS.DL (March 21, 1996)

This patch restores that portion of the flight software patched by PATCHEN.DL to its original state to allow spacecraft mode commands to operate correctly.

AUTOX.DL (March 21, 1996)

Patch to allow the autosensitivity routine to command the -15 kV supply DAC to 0 when commanded to be disabled. This patch replaces the autos_processor() function in the IMP. Additional RAM space is not used by this patch.

PSI Command/ Monitor Patches (April 12, 1996)

The PSI monitor function patch consist of the following patches:

PSIMON.DL
PSIJMP.DL
PSIK_EN.DL
PSIMONDS.DL
PSICHLMT.DL

1) PSIMON.DL

This is the actual IMP code patch for implementing the PSI command/monitoring function. This code is placed at the end of the normal code in TIDE RAM. This code will not execute until the PSIJMP patch is transmitted.

The PSI monitor patch recodes the psi_command code block of the interrupt processor function in the IMP. The new code and its associated data tables use 1328 (decimal) bytes of RAM starting at address 0x4f92a (after the original IMP code).

The following are the design features of the PSIMON.DL patch to support command updating of the PSI power supplies and on-board limit checking of each supply. PSIJMP.DL patch is required after transmission of the PSIMON.DL patch for the patch to operate.

- Each level of each of the supplies (heater, keeper and discharge) have an upper and lower limit for supply current monitor. When enabled, the current monitoring function checks each power supply's current for upper and lower exceedances. Once a monitor exceeds the upper or lower limit for that state level, the software will command all three power supplies off and disable the monitoring function. The power supplies can then be commanded to the desired states and the dataloads for enabling current monitoring is required to be transmitted to re-enable the current monitoring function. Each limit has an associated flag to determine which supply and what limit caused the power supply to shut down.

- Each supply has its own monitoring enable/disable command. This command will be implemented using patches (e.g. PSIK_EN.DL).

- Each supply is updated with the current commanded level at least 4 times per 9.2 second major frame. One supply is updated 5 times per major frame. The supplies are commanded on an uneven interval each major frame. Each power supply is updated approximately every 2 seconds.

Note: The current monitor checking should be disabled (PSIMONDS.DL) whenever the supplies are being commanded from the ground to a new level or being turned off. This action will avoid any hysterisis problems when changing to new levels.

2) PSICHLMT.DL

This patch is provided to allow changes to the default low/high limits for the discharge, heater, and keeper supplies in the PSIMON.DL patch. The patch listed below present the default limits for each supply. The comment for each line describes the field position for each supply's high and low limit for each power supply state. Each limit is an 8-bit value. If a value of 0FF hex is established as the limit, the software will not take action on upper limit exceedances due to the monitor being at full scale.

```
B227c98008    ; IMP addr 0x4F930-8 cmd words
B300000018    ; 24 data bytes in load
B3FF561C00    ; D Lvl 2 high/low | D Lvl 0 high/low
B3FF80AB39    ; D Lvl 3 high/low | D Lvl 1 high/low
B3E64C1700    ; H Lvl 2 high/low | H Lvl 0 high/low
B3F8528F2F    ; H Lvl 3 high/low | H Lvl 1 high/low
B3D9482400    ; K Lvl 1 high/low | K Lvl 0 high/low
B3FF7AFF71    ; K Lvl 3 high/low | K Lvl 2 high/low
B3DE0210F9    ;CHECKSUM
```

3) PSIK_EN.DL

This patch enables monitoring of the Keeper supply by the patch PSIMON.DL. The third command in the patch directs the software to which supply would be enabled. As can be seen in the third command of the patch below, a zero byte shall follow the B3. A non-zero entry in any of the next three byte locations will enable the Keeper, Heater and/or the Discharge supply. In this patch, a 01 is used to enable keeper supply monitoring while leaving the monitoring of the Discharge and Heater supply disabled.

```
B227C96003    ; IMP addr 0x4f92c-3 cmd words
B300000004    ; 4 data bytes in load
B300010000    ; pad (always 0)/keeper/heater/discharge
B327CA6007    ;CHECKSUM
```

4) PSIMONDS.DL

This is the same patch as the PSIK_EN.DL with the exception that in the third command shown above the byte field is a zero. This patch when transmitted disables current monitoring of all three PSI supplies.

STOPS1A.DL/STOPS1B.DL (November 22, 1996)

The STOPS1A.DL patch followed by the STOPS1B.DL patch allows the software to acquire and organize the Stop data channels into a data product. The Stop data channels appear in the mass 4 detector 4 allocation of the data product (1024 data values if the no collapse option is used). Mass 4, detectors 1,2,3,5, and 6 will contain zeros. The Stop data is organized in the same angle/energy order as all other start singles and mass data.

IV. STATUS OF CONTRACT REQUIRED DELIVERABLES

A. Following is a list of deliverable data required by the contract.

Item No.	Description	Status
1.0	Performance Assurance Implementation Plan	Submitted with proposal
2.0	Data for GSFC Flight Assurance Reviews:	
	a. Copies for review team of material presented at review	Provided at beginning of review meeting

3.0	Verification Plan	
	a. Preliminary	Submitted with proposal
	b. Final	Available at time of GSFC Flight Assurance CDR
3.1	Verification Specification	
	a. Preliminary	Submitted with proposal
	b. Final	Available at time of GSFC Flight Assurance CDR
3.2	Verification Procedures	Developed before the particular test activity for subsystem, and payload levels
3.3	Verification Reports	Produced after completion of activity
4.0	Fracture Control Implementation Plan	Preliminary copy submitted with proposal Submitted final at time of GSFC Flight Assurance PDR
4.1	Operations Hazard Analyses	Available before an activity or use of a facility
4.2	Payload Safety Noncompliance Report	Available as generated
4.3	Safety Compliance Data Package	
	Phase 0	Available before GSFC Flight Assurance SCR

	Phase 1	Available before GSFC Flight Assurance PDR
	Phase 2	Available before GSFC Flight Assurance CDR
	Phase 3	Available befor GSFC Flight Assurance FRR
4.4	Launch Site Safety Plan	Not required
5.0	Nonstandard Parts and Devices Data Package	Developed before procurement or use
5.1	Contractor DPA Procedures and Requirements	Developed before use
5.2	Parts/Devices Identification List	1. Submitted after contract award
		2. Available at PDR
		3. Available at CDR
6.0	Data supporting cured, out-of-date materials	None used
6.1	Data on Nonconventional Application of Materials	None used
6.2	Engineering Drawings for Materials Application	Upon request
6.3	Materials List (Inorganic and Polymeric), Lubrication List, Processes List	
	a. Preliminary	Available at PDR
	b. Final	Available at CDR
	c. Updates	As needed
7.0	Failure Modes, Effects, and Criticality Analyses	
	a. Preliminary	Submitted at PDR
	b. Final	Available at CDR

	c. Updates	As required
7.1	Trend Analyses	
	a. List of parameters to be monitored	Available at time of GSFC Flight Assurance CDR
	b. Trend Analysis Reports	Available at time of GSFC Flight Assurance PER and FRR
7.2	Limited-Life List	
	a. Preliminary	Available before PDR
	b. Final	Available before CDR
	c. Updates	As changes were made
8.0	Fabrication and Assembly Flow Plan	
	a. Preliminary	Not required
	b. Final	Not required
8.1	Electrostatic Discharge Control Plan	
	a. Preliminary	Submitted before PDR
	b. Final	Submitted before CDR
8.2	MRB Decision on Nonconformance	As generated
8.3	Request for Repair/Use-As-Is	As generated
8.4	Standard Repair Procedures	As generated
8.5	Malfunction/Failure Reporting	
	a. Notification	Submitted orally within 24 hours
	b. Written Notification (MR Form)	Available

	c. Failure Analysis, Proposed Corrective Action	Orally
8.6	Malfunction/Failure Report Close-Out	Documented at completion of required actions
8.7	Response to Alerts	Responded after receipt of notification
8.8	Alerts	Took action as required.
8.9	Procedures for Handling, etc.	
	a. Preliminary	Generated before GSFC Flight Assurance CDR
	b. Final	Developed before use
8.10	Acceptance Data Package for each End-Item comprising:	Submitted at time of delivery of end-item
	a. As-Built Configuration List	
	b. List of Parts/Devices used in the hardware	
	c. List of Materials and Processes which were used in the hardware	
	d. Test Log Book including total operating time and cycle records	
	e. List of Open Items with reasons for items being open	
	f. Safety Compliance Data Package	
	g. Listing and status of all identified Life-Limited Items	
	h. Critical Parameters Trend Data	
	i. Results of the Final Comprehensive Performance Test	

9.0	Contamination Control Plan	
	a. Preliminary	Submitted with proposal
	b. Final	Available at time of GSFC Flight Assurance CDR

B. Deliverable Items and Schedules

Item No.	Description	Status
1	Protoflight TIDE Instrument	3 May 1995
2	Thermal Analytical Models	Submitted before CDR
3	Structural Analytical Model	Submitted before CDR
4	Mechanical and Electrical Ground Support Equipment	3 May 1995
5	Instrument Flight Software	3 May 1995
6	Integration and Test Software	3 May 1995
7	Instrument(s) Operations Software	Through 30 Apr 1997
8	Technical Support	As required
9	Reviews and Meetings	As required
10	Documentation per CDRL	As required
11	Software Performance Assurance Implementation Plan	1 June 1993

C. Report Deliverables

Item No.	Description	Status
1	Monthly Technical Progress Reports	Submitted monthly
2	Monthly Cost Status Reports	Submitted monthly
3	Final Report	16 May 1997

V. SUBCONTRACTS

The following subcontracts were implemented:

A.	Hughes Aerospace 3011 Malibu Canyon Rd. Malibu, CA 90265	$398,143	Successfully executed and now closed.
B.	Starsys Research 5757 Central Ave. Boulder, CO 80301	$ 91,600	Successfully executed and now closed.
C.	Rice University PO Box 1892 Houston, TX 77251	$ 43,906	Successfully executed and now closed.